BOUNDS ON $\Delta B = 1$ COUPLINGS IN THE SUPERSYMMETRIC STANDARD MODEL

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ABSTRACT

The most general supersymmetric model contains baryon number violating terms of the form $\lambda_{ijk}\ \overline{D}_i\ \overline{D}_j\ \overline{U}_k$ in the superpotential. We reconsider the bounds on these couplings, assuming that lepton number conservation ensures proton stability. These operators can mediate $n-\overline{n}$ oscillations and double nucleon decay. We show that neutron oscillations do not, as previously claimed, constrain the λ_{dsu} coupling; they do provide a bound on the λ_{dbu} coupling, which we calculate. We find that the best bound on λ_{dsu} arises from double nucleon decay into two kaons. There are no published limits on this process; experimenters are urged to examine this nuclear decay mode. Finally, the other couplings can be bounded by the requirement of perturbative unification.

In the standard electroweak model, conservation of baryon number and lepton number arises automatically from gauge invariance. This is not the case in supersymmetric models, however. In the most general low-energy supersymmetric model, one has terms which violate lepton number and terms which violate baryon number. Since the presence of both of these may lead to unacceptably rapid proton decay, one or both must generally be suppressed by a discrete symmetry. In the most popular model, R-parity, given by $(-1)^{3B+L+F}$ is imposed, leading to baryon and lepton number conservation. However, there is no *a priori* reason that R-parity must be imposed, it is quite possible that only one of the quantum numbers is conserved. There has been extensive discussion of the possibility that lepton number is violated, but relatively little investigation of the possibility that lepton number is conserved and baryon number is violated.

In this case, a term will appear in the superpotential given by $\lambda_{ijk}\,\overline{D}_i\,\overline{D}_j\,\overline{U}_k$ where the indices give the generation number and the chiral superfields are all righthanded isosinglet antiquarks. Since the term is symmetric under exchange of the first two indices, and is antisymmetric in color, it must be antisymmetric in the first two flavor

indices, leaving nine couplings which will be designated (in an obvious notation) as λ_{dsu}, λ_{dbu}, λ_{sbu}, λ_{dsc}, λ_{dbc}, λ_{sbc}, λ_{dst}, λ_{dbt} and λ_{sbt}.

There are many models in which low energy baryon number is violated and yet lepton number is conserved; the most familiar are some left-right symmetric models. It is widely believed that the strongest bound on B-violating operators comes from neutron oscillations, which violate B by two units. The first discussion on the effects of some of these operators in supersymmetric models used neutron oscillations to bound λ_{dsu} and λ_{dbu}; this result remains widely cited today.

In this talk, I will discuss the most stringent bounds that can be placed on these nine couplings. First, it will be pointed out, in contrast with previous claims, that neutron oscillations do *not* provide any significant bound at all on the λ_{dsu} coupling, due to a suppression factor which was neglected in the original calculation. This suppression is less severe for the λ_{dbu} coupling, and we will obtain a bound in that case. It will then be pointed out that the strongest bound on the λ_{dsu} coupling will come from limits on double nucleon decay (in a nucleus) into two kaons of identical strangeness, and will estimate the bound. Finally, the recent work of Brahmachari and Roy noted that the λ_{dbt} and λ_{sbt} couplings can be bounded by requiring perturbative unification; we will extend their work to cover all of the additional couplings. This work will appear in Physics Letters B in March or April of 1995; the reader is referred there for the details of the calculation and for a list of references (which are neglected here due to space limitations).

In the first attempt to place a bound on some of the above operators considered the effect of the λ_{dsu} and λ_{dbu} terms on neutron oscillations through the process ($udd \to \tilde{\overline{d}}_i d \to \tilde{g} \to \tilde{d}_i \overline{d} \to \overline{u}\ \overline{d}\ \overline{d}$), where $\tilde{d}$ is a squark and $\tilde{g}$ is a gluino. The effects of intergenerational mixing were included by putting in an arbitrary mixing angle, assigned a value of 0.1. However, there is a much more severe suppression factor which results in this process giving no significant contribution to neutron oscillations.

Consider the term $\lambda_{dsu}\overline{D}\ \overline{S}\ \overline{U}$. It violates B by one unit and strangeness (S) by one unit. However, it conserves B-S. Since neutron oscillations violate B but not S, strangeness violation must appear elsewhere in the diagram. This means that there must be flavor-changing electroweak interactions (involving either a W or a charged Higgs or chargino) in the diagram. Since only isodoublets participate in the weak interactions, and the baryon number violating term has only isosinglets, there must be mass insertions (on the squark lines)–at least two in the simplest case. Thus, there will be electroweak interactions in the diagram, and an additional suppression factor of m_s^2/m_W^2, where m_s is the strange quark mass. This makes the contribution of the λ_{dsu} term highly suppressed. (Note: off-diagonal gluino couplings are generally much smaller, and will not contribute significantly).

The contribution involving the λ_{dbu} terms will only be suppressed by m_b^2/m_W^2, which is not negligible. The leading contribution is from a box diagram in which a $\tilde{b}_L$ and a $\overline{d}_L$ turn into a $\tilde{\overline{b}}_L$ and a d_L; the $\tilde{b}_L$ arises from the λ_{dbu} coupling with a mass

insertion on the squark line. We have calculated this contribution (see the Physics Letters paper for details), and find a bound on λ_{dbu} which varies from .002 and .1 as the squark mass varies from 200 GeV to 600 GeV. For squark masses above a TeV, no useful bound emerges.

The best bound on the λ_{dsu} term arises from double nucleon decay into two kaons, which violates both B and S, but not B-S. Thus, mass insertions and electroweak interactions are unnecessary. Here, the diagram simply involves having two λ_{dsu} interactions turns u and d quarks into s anti-squarks, which exchange a gluino and turn into s antiquarks; the spectators then form the two kaons. Taking the limit on the rate to be 10^{30} years, we find the bound to be $\lambda_{dsu} < 10^{-15} R^{-5/2}$, where R is roughly the ratio of a hadronic scale to the squark mass; for a hadronic scale of 300 MeV and a squark mass of 300 GeV, this bound is 10^{-7}. A similar bound was obtained by assuming that a neutron could oscillate into a $\overline{\Xi}$, which then annihilates with another neutron in the nucleus to produce two kaons. Note that there is currently no published bound on this decay; experimenters at Kamiokande are currently analysing the possibility, by considering the decay of the oxygen nuclei in their detector to carbon-14 and two charged kaons.

What about the other seven couplings? It was recently noted by Brahmachari and Roy that in a unified theory precise bounds can be obtained by requiring that the couplings be perturbative up to the unification scale. We have generalized their results (which applied only to two of the couplings) to all seven, and find an upper bound of 1.25 on each of them (the bound actually applies to the square root of the sum of the squares of combinations of three of the couplings, so is a bit stronger), with a slightly stronger bound for couplings involving the top quark. Note that if the fixed point is saturated for one of these couplings (as may be the case for the top quark Yukawa coupling), then this bound would, in fact, be the value of the coupling at low energy, in which case the scalar quarks would have to be heavier than the top quark in order to avoid the domination of top quark decays into a light quark and a squark.

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